Europäisches Patentamt
European Patent Office
Office européen des brevets

(19) (11) Publication number: **0 236 519 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 86103153.2

(22) Date of filing: 08.03.86

(51) Int. Cl.⁴: H04N 5/14

(43) Date of publication of application: 16.09.87 Bulletin 87/38

(84) Designated Contracting States: DE FR GB IT NL SE

(71) Applicant: ANT Nachrichtentechnik GmbH
Gerberstrasse 33
D-7150 Backnang(DE)

(72) Inventor: Bierling, Matthias
Eichstrasse 42
D-3000 Hannover 1(DE)
Inventor: Thoma, Robert
Tempelhofer Strasse 11
D-3012 Langenhagen 1(DE)
Inventor: Musmann, Hans-Georg, Prof. Dr.
Heckenrosenweg 24
D-3320 Salzgitter-Bad(DE)

(74) Representative: Schickle, Gerhard, Dipl.-Ing.
ANT Nachrichtentechnik GmbH Patent- und Lizenzabteilung Gerberstrasse 33
D-7150 Backnang(DE)

(54) Motion compensating field interpolation method using a hierarchically structured displacement estimator.

(57) A motion compensating field interpolation method is presented, which allows to interpolate several fields between every two transmitted fields of a digital television sequence. Using the model of translatorily displaced objects a hierarchically structured displacement estimator is applied to cope with relatively large displacements. It provides a displacement vector with integer components for each picture element of the fields to be interpolated. A change detector is used to assure zero displacement vectors in unchanged areas. A two-coefficient spatio-temporal filter interpolates each picture element of the fields to be interpolated. By experimental evaluations the model of pure translatorily displaced objects has proven to be sufficient to approximate many kinds of motion. The presented interpolation technique allows the unblurred reconstruction of omitted fields of television sequences, widely preserving the natural impression of motion.

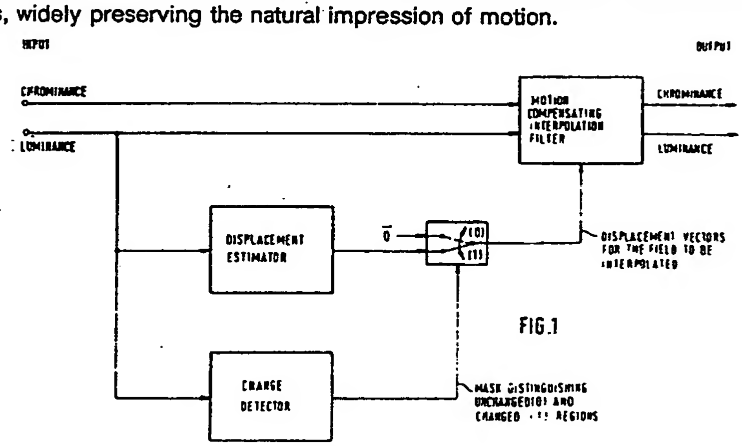


FIG.1

EP 0 236 519 A1

Motion compensating field interpolation method using a hierarchically structured displacement estimator

Background of the Invention:

The present invention relates to a method for a motion compensating field interpolation as well as the use of this method. Such a method is particularly suitable for the reconstruction of omitted fields of television sequences.

The problem of interpolating fields in digital television sequences arises in the case of field frequency conversion. In source coding applications fields have to be reconstructed, which are dropped in the coder to allow a transmission of television signals in digital channels with very low transmission bit rates. The CCITT Study Group XV is currently investigating television codecs with 384 kbit/s transmission rate. The aim is to provide video conference services using the Integrated Services Digital Network ISDN. In order to achieve this data rate it seems to be necessary to reduce the number of transmitted fields in addition to known source coding techniques. A recently presented work on this subject uses a field subsampling by a factor of 4:1 combined with a hybrid coding algorithm [1]. Then, at the receiver three fields have to be interpolated between every two transmitted fields.

The problem is to generate a field at a given temporal position between two successive fields of a television sequence. Since the temporal luminance changes are oftentimes caused by moving objects, a simple field repetition technique, which inserts the nearest available field, yields jerkily moving objects [2]. Another simple approach is linear interpolating by temporal filtering [3]. In this case for each picture element to be interpolated a weighted average of the corresponding picture elements at the same spatial position is calculated. This interpolation technique is able to adapt to luminance changes which, e.g. are only due to illumination changes of the scene contents. However, blurring becomes visible in moving areas depending on the amount of motion.

Hence, motion compensating interpolation (MCI) techniques have been developed, which are recently reviewed in [4]. MCI-techniques take into account the motion of objects to preserve the natural impression of motion. The main difficulty is to provide a sufficiently precise estimation of the motion parameters. In order to limit the complexity of the algorithm, most of the MCI-techniques are based on the assumption of pure translatorily displaced objects in the image plane [1,5-7], as well as the presented technique. In [1] and [5] the images are subdivided into a fixed number of rectangular blocks. One displacement vector is determined for each block belonging to a moving area, whereas in [6] only one representative displacement vector is determined for each moving area. The algorithm, described in [7], proposes the estimation of one displacement vector for each picture element in the moving image parts, to obtain an improved rendition of motion in the reconstructed television sequence.

Summary of the Invention:

It is an object of this invention to provide a method as described in the preamble of patent claim 1 which copes with large displacements.
It is another object of this invention to provide uniquely defined displacement vector fields, which are valid for the temporal positions of the fields to be interpolated rather than for the transmitted fields.
A further object of this invention is to present suitable applications of this method.
The invention is characterised by the features of the claims.

The invention describes the complete algorithm of a motion compensating field interpolator, that is applicable for the reconstruction of omitted fields, e.g. in a video conference codec. The hierarchically structured displacement estimation technique combined with a change detector copes with large displacements, which occur even in typical video conference sequences, if several successive fields have been dropped at the transmitter. In contrast to the algorithm in [7] this technique provides uniquely defined displacement vector fields, which are valid for the temporal positions of the fields to be interpolated rather than for the transmitted fields. This further reduces the jerkiness in the motion compensating interpolated sequence. The displacement estimation technique is based on the differential displacement estimation algorithm described in [8].

Brief Description of Drawings

The features and advantages of the invention will be more apparent from the detailed description hereunder taken in conjunction with the accompanying drawings, wherein:

Fig. 1 shows the principle of the motion compensating field interpolator.

Fig. 2 illustrates the translatory displacement in television sequences. An object has been displaced from field k-l to field k by a vector D with the components dx,dy.

Fig. 3 illustrates several motion compensating iteration techniques for displacement estimation using displaced measurement windows.

(a) measurement window in field k is displaced.

(b) measurement window in field k-l is displaced.

(c) measurement windows are displaced symmetrically against each other.

Fig. 4 illustrates two distinct measurement windows placed in two successive field k-l (a) and k (b). The windows are of size 65 by 65 and 13 by 13 picture elements, respectively.

Fig. 5 is a 3-D plot of the approximated expectation of the squared displaced frame difference (z-axis) versus the displacement vector components dx,dy (x-and y-axis). The results have been obtained by displacing the measurement windows placed in the field shown in Fig. 4 (a) to all positions up to 20 picture elements around the shown initial position (x=0,y=0) in the horizontal (y-) and vertical (x-) direction. The windows placed in the field shown in Fig. 4 (b) were fixed.

(a) The windows of 13 by 13 picture elements have been used.

(b) The windows of 65 by 65 picture elements have been used. The image signal covered by the windows has been bandlimited by a FIR filter (FILI Table 2) and subsampled by a factor of 4:1 in horizontal and vertical direction.

Fig. 6 illustrates the change detection for the case of a one-dimensional signal.

Fig. 7 is a block diagram of the change detector.

Fig. 8 illustrates the change detection mask, obtained by evaluating the frame difference signal shown in Fig. 9 (b). Unchanged areas are black displayed. The image contents of the first of two consecutive transmitted fields are inserted in the changed areas.

Fig. 9 illustrates of the motion compensating interpolation filter. The picture element at x_o,y_o in the field to be interpolated is calculated by a weighted sum of the picture elements in field k and k-l, connected by the displacement vector D.

Fig. 10 demonstrates the motion compensating field interpolation for the case of transmitting every fourth field. All fields shown, are taken from the temporal centered position between two consecutive transmitted fields. The luminance components only are displayed.

(a) Original field of the sequence "Trevor".

(b) Frame difference signal caused by the luminance changes between the transmitted fields. Positive and negative differences are displayed with white and black luminance values, a zero difference is gray displayed.

(c) The field generated by linear interpolation without motion compensation.

(d) The field generated by motion compensating interpolation. The hierarchically structured displacement estimator with the parameters listed in Table 1 has been used.

Fig. 11 demonstrates of the motion compensating field interpolation for the sequence "Split Screen". All simulation and display parameters are the same as in Fig. 9

(a) Original field of the sequence.

(b) Frame difference signal.

(c) The field interpolated without motion compensation.

(d) The field motion compensating interpolated.

Table 1 shows the parameters for the hierarchically structured displacement estimator as used for the simulations.

Table 2 shows the impulse responses of the digital FIR filters used for the bandlimitation of the image signal.

Detailed Description of the Invention:

1. General structure of the interpolator

First the whole structure of the motion compensating field interpolator is outlined. It consists of three blocks: displacement estimator, change detector and motion compensating interpolation filter. These blocks are described in detail in Sections 3, 4 and 5. Experimental results based on the interpolation of more than 180 fields by means of computer simulations, are discussed in Section 6.

2. Structure of the motion compensating interpolator

The motion compensating field interpolator consists of a displacement estimator, a change detector, and a motion compensating interpolation filter as shown in Fig. 1. The input data is a digital television sequence containing luminance and chrominance components in fields without lineinterlace. For the case, that fields of a sequence are lineinterlaced, a vertical filtering of every second field can be applied to obtain a non-interlaced format.

The interpolation algorithm is based on an image model, which is restricted to rigid objects translatorily displaced in the image plane. A displacement estimator calculates a displacement vector for each picture element of a field to be interpolated at a given temporal position between two available fields. A change detector distinguishes between changed and unchanged regions of the image contents. This information is used to assign zero displacements to the picture elements in unchanged areas. Thus, erroneously non-zero estimated vectors in these regions are eliminated. Only the luminance data is used for displacement estimation and change detection.

Each displacement vector is determined in the way, that it connects two picture elements of two available fields and crosses the spatial position of the picture element to be interpolated. In the motion compensating interpolation filter a weighted sum of the picture elements, connected by the displacement vector, is calculated for each picture element of the field to be interpolated. The displacement vectors, calculated by means of the luminance data only, are used for both, the interpolation of the luminance signals and the interpolation of the chrominance signals.

3. Displacement estimator

3.1 The basic estimation algorithm

The estimation algorithm is based on the assumption of a translatorily displaced rigid object in the image plane, that does not change its luminance from field k-l to field k, as shown in Fig. 2 . Then, for a moving area the equation

$S_{k-l}(x,y) = S_k(x+dx,y+dy)$ (1)

holds, where $S_{k-l}(x,y)$ denotes the luminance in field k-l at the spatial position x,y and $S_k(x+dx,y+dy)$ is the corresponding luminance, displaced by a vector **D** with the components dx,dy in field k. Thus, a moving object causes a frame difference signal FD, where

$FD(x,y) = S_k(x,y) - S_{k-l}(x,y)$. (2)

Compensating the displacement by an estimated displacement vector $\hat{D}$ with the components $\hat{d}x$, $\hat{d}y$ the remaining frame difference, called displaced frame difference DFD, results as

$DFD(x,y,\hat{D}) = S_k(x+\hat{d}x,y+\hat{d}y) - S_{k-l}(x,y)$. (3)

Under the above mentioned assumptions, the DFD approaches to zero if the estimate $\hat{D}$ is close to the true displacement vector **D**. In [8] an estimation algorithm is derived, that minimizes the local mean squared displaced frame difference. The estimated displacement vector components are determined as

$$\hat{d}x = \{ E[\bar{G}_x \cdot \bar{G}_y] \cdot E[FD \cdot \bar{G}_y] - E[FD \cdot \bar{G}_x] \cdot E[\bar{G}_y^2] \} / DEN$$

$$\hat{d}y = \{ E[\bar{G}_x \cdot \bar{G}_y] \cdot E[FD \cdot \bar{G}_x] - E[FD \cdot \bar{G}_y] \cdot E[\bar{G}_x^2] \} / DEN$$

with the denominator (4a)

$$DEN = E[\overline{G}_x^2] \cdot E[\overline{G}_y^2] - E^2[\overline{G}_x \cdot \overline{G}_y],$$

where the coordinates x,y are omitted for simplicity. The components

$\overline{G}_x(x,y) = \{\delta S_k(x,y)/\delta x + \delta S_{k-1}(x,y)/\delta x\} / 2$

$\overline{G}_y(x,y) = \{\delta S_k(x,y)/\delta y + \delta S_{k-1}(x,y)/\delta y\} / 2$ (4b)

are averages of first order derivatives of the luminance signal of two successive fields with respect to the coordinates x and y, respectively. The algorithm given by eq. (4) has been derived using a two-dimensional polynomial of second order as an image model for the luminance signal $S_k(x,y)$ and $S_{k-1}(x,y)$. Due to this image model the precision of the estimate is improved compared to other known algorithms [7,9], as shown in [8]. Of course, in digital video processing the expectations in eq. (4) have to be approximated by summing over measurement windows of a certain size. Usually these measurement windows are rectangular and an estimation obtained from eq. (4) is then assigned to the center of the window. Also the spatial gradients have to be approximated by means of the samples of the luminance signal. Adopting a proposal from [10], the spatial derivatives are approximated as one half of the differences between the two adjacent picture elements in the x-and y-direction, respectively.

It should be noted, that all vector components obtained by eq. (4) are rounded to the nearest integer value. Thus, we do not have any non-integral vector component. Neither in displacement estimation nor in motion compensating field interpolation we have to perform any spatial interpolation of picture elements between the lattice elements of field k-l or field k. A signal containing any translatory motion in the image plan can be perfectly interpolated using integral displacement vector components, as shown in [11].

3.2 Motion compensating iteration

A displacement estimate, obtained by evaluating a differential estimation algorithm, is often far away from the true displacement, even if the present motion is restricted to pure translatory motion. This is due to the fact, that the actual image signal differs drastically from the mathematical image model the algorithm is based on. In this case, the displacement estimate can be improved by a motion compensating iteration of the estimation algorithm, as explained in the following. To obtain an estimate for the vector that indicates the displacement of an object, displaced from an arbitrary position x_o, y_o in the field k-l to the unknown position x_o+dx, y_o+dy in field k, the measurement windows are placed in the way, that the centers are given by x_o, y_o for both fields. The five distinct expectations needed for eq. (4a) are approximated by summing over these so placed windows. After calculating the components $\hat{d}x$, $\hat{d}y$ the estimate can be improved by a motion compensating iteration of the algorithm. For that purpose, the frame difference is compensated by the vector estimated up to now, i.e. by the vector obtained in the first step of iteration. This is done by displacing the measurement window in field k to the position $x_o+\hat{d}x, y_o+\hat{d}y$ and calculating again the five expectations. The frame difference FD in eq. (4a) is then changing into the displaced frame difference DFD given by eq. (3) as a function of the components $\hat{d}x$, $\hat{d}y$ calculated before. Moreover, all terms belonging to field k have to be taken from the displaced position including the spatial derivatives of $S_k(x,y)$. The displacement vector calculated in this second step is added to the vector obtained in the first step of iteration. This procedure is repeated until a sufficiently precise estimation is achieved.

This kind of iteration technique, illustrated in Fig. 3 (a), applied to all picture elements of field k-l yields a displacement vector field that is uniquely defined for field k-l. However, it does not assign a displacement vector to all picture elements of field k. To obtain a vector field uniquely defined for field k, the measurement windows placed in field k are fixed, those in field k-l are displaced in the motion compensating iteration, as shown in Fig. 3 (b).

3.3 Symmetrized motion compensating iteration

For motion compensating interpolation of a field at an arbitrary temporal position between two successive fields of a television sequence, a uniquely defined displacement vector field for the field to be interpolated is needed. Using the iteration technique described in Section 3.2 we obtain a vector field that is defined either for field k-l or for field k. Thus we do not have the assignment of displacement vectors to all picture elements of the field to be interpolated. In order to overcome this problem a symmetrized iteration technique is adopted [12], which is examplarily explained for a field at the centered temporal position

between field k-l and k in Fig. 3 (c). In the second step of the motion compensating iteration both measurement windows are displaced against each other. For this example the window in field k is displaced to the position $x_0 + \hat{d}x/2, y_0 + \hat{d}y/2$ and that in field k-l to $x_0 - \hat{d}x/2, y_0 - \hat{d}y/2$. Thus, a displace ment vector is obtained which is connecting an object displaced from field k-l to field k and which is crossing the spatial position x_0, y_0, the vector is to be estimated for. This approach can also be applied to fields at other temporal positions between two successive fields. The symmetrized iteration technique yields a displacement vector field, that is uniquely defined for all picture elements of a field to be interpolated at a given temporal position.

In order to avoid any spatial interpolation of picture elements between the lattice elements of the fields, both measurement windows have to be displaced by an integer number of picture elements in each step of iteration. Thus, for the example shown in Fig. 3 (c), the motion compensating iteration by displacing the measurement windows symmetrically against each other, always yields displacement vector components, that are a multiple of 2 picture elements. At non-centered temporal positions between field k and k-l the set of possible values for the displacement vector components is further restricted. For example at the temporal position of one fourth of the field distance to field k-l, the vector components are a multiple of 4 picture elements. To overcome this problem, a special procedure for the motion compensating interpolation of three fields between every two given fields is applied, as described in Section 6.2.

3.4 Spatial and temporal recursion

One can decrease the number of iterations needed to obtain a sufficiently precise estimation by recursion techniques. A recursive estimation starts like the second step of iteration as described in Section 3.2. For a spatial recursion an initial guess obtained by means of displacement vectors previously calculated for adjacent picture elements serves for the first motion compensation step. Thus, only an update term is determined and added to the initial vector. This technique has been investigated by several authors, e.g. [13]. A temporal recursion is performed by using the displacement vector field determined for the previous field of the image sequence. An algorithm described in [14] makes use of this technique. Both, spatial and temporal recursion techniques involve the risk of estimation error propagation at object boundaries and in the case of non-stationary moving objects.

For the present, these kinds of recursive techniques are not considered in the motion compensating interpolation algorithm described here.

3.5 Hierarchically structured displacement estimator

One of the most critical parameters of a differential displacement estimator is the size of the measurement window used for the approximation of the expectations. The largest window we can use covers the entire image, and we only obtain a reasonable displacement estimation if the whole picture contents are displaced as one moving object, e.g. in the case of panning. However, for the purpose of motion compensating interpolation an estimate locally approximating the present motion at each picture element is needed rather than a mean value of displacements caused by several moving objects. On the other hand, using very small windows, e.g. of 3 by 3 picture elements, the estimate tends to be unreliable. In the case of large displacements there may be no correspondence between the contents of these small windows, placed in two successive fields of a television sequence. That means, these windows contain two absolutely different image parts, and the evaluation of the differential estimation algorithm does not make any sense. The differential estimation of the displacement vector for a moving object, covered only by one of the measurement windows, is impossible. Moreover, using small windows the expectations are approximated insufficiently and we are able to cope with displacements of one or two picture elements at the most. Thus, large measurement windows are needed to cope with large displacements. On the other hand, small windows are required to be sufficiently local adaptive.

In order to overcome this problem a hierarchically structured displacement estimator has been developed. A motion compensating iteration as described in Section 3.2 and 3.3 with large window sizes in the first steps of iteration is applied. The image signal is filtered by FIR lowpass filters in these first steps. From one step to another step of iteration the window size is decreased and the filtering is reduced. The first steps of iteration serve to cope with large displacements. The filtering provides an image signal, which is matched to the image model the estimation algorithm is based on. Thus the estimate becomes less precise in favour of an increased reliability. After motion compensation by means of the vector estimated in

the first steps of iteration, the residual displacement has to be estimated in the next steps more precisely. The smaller the residual displacement the smaller the window sizes can be choosen avoiding the risk of estimation errors. Being close to the actual displacement to be estimated, the algorithm is evaluated on the unfiltered image signal.

To limit the computational complexity in the first steps of iteration the picture signal is spatially subsampled according to the bandlimitation achieved by the FIR filtering. This can be done in a way, that the number of picture elements involved by the measurement windows is identical in each step, although the image part covered by the windows differs from one to another step of iteration.

In the following an example is given to demonstrate the influence of the window size to the reliability of the estimate. Fig. 4 shows two successive fields of a television sequence. We consider the estimation of the displacement vector for the picture element given by the center of the measurement windows placed at the same spatial position in field k-l (Fig. 3.3(a)) and in field k (Fig. 4 (b)). Two distinct window sizes are used, one of 13 by 13, the other of 65 by 65 picture elements. As mentioned in Section 3.1 the expectation of the squared displaced frame difference is applied as an optimization criterion for the estimate. The algorithm uses a spatio-temporal gradient method to estimate the minimum of this expectation. Fig. 5 shows the 3-D plot of the optimization criterion versus the displacement vector components dx,dy. The results have been obtained by displacing the measurement windows in field k-l horizontally and vertically to all positions up to 20 picture elements around the initial position. The windows in field k were fixed. The window size of 13 by 13 picture elements obviously is too small in order to recognize a definite minimum (Fig. 5 (a)). In fact, the algorithm results in an estimate $\hat{d}\,y=0$ in contrast to the actual displacement of about 8 picture elements. The result shown in Fig. 5 (b) has been obtained by using the window size of 65 by 65 picture elements. In this case, the image signal covered by the windows has been bandlimited by a FIR filter and subsampled by a factor of 4:1 horizontally and vertically. The minimum of the optimization criterion can be identified clearly but not precisely. The accuracy of the estimate can be increased in a second step of iteration using smaller measurement windows and evaluating the algorithm on the unfiltered image signal.

4. Change detector

4.1 Principle of change detection

The change detector distinguishes between temporally changed and unchanged regions of two successive fields. The assignment of picture elements of these fields to the changed area is oftentimes wrong, because of scene inherent noise in the unchanged area. The aim of the change detector is to decide whether the temporal changes are caused by noise or by relevant changes due to motion of objects or illumination changes.

For this purpose known change detection algorithms [2,13] evaluate the frame difference for every picture element of the two successive fields. If the frame difference exceeds a given threshold the picture element is assigned to be changed, otherwise to be unchanged. Thus, the change detector provides a binary mask indicating changed and unchanged areas of the two successive fields.

However, this detection is affected by the appearance of noise, i.e. picture elements are assigned to the changed region but belong to the unchanged region or vice versa. To overcome this problem, the frame differences are summed up over a measurement window and the outcome is compared with a given threshold [2,3]. This operation leads to binary masks with changed areas, much larger than effectively caused by the moving object or to boundaries, frayed out between unchanged and changed regions.

Fig. 6 illustrates the change detection using a one-dimensional signal as an example . An object has been moved by a displacement dx from field k-l to field k. The absolute frame differences are compared with a threshold of zero, assuming a noiseless signal. The resulting change detection mask distinguishes between changed and unchanged regions. As shown in Fig. 4.1, this mask borders on the left-hand boundary of the object in field k-l and on the right-hand boundary of the displaced object in field k.

4.2 The change detection algorithm

Fig. 7 shows the blockdiagram of the change detector, that determines the frame differences and performs a threshold operation, an elimination of singular uncertain elements, a median filtering, and an elimination of singular elements.

First, the frame difference between field k and field k-l is calculated, as defined in eq. (2). Evaluating the absolute frame difference for each picture element independently, one of three states unchanged $C_1=0$, changed $C_1=1$, or uncertain $C_1=X$ is assigned to each element of an image. Using the uncertain state $C_1=X$, misdecisions caused by noise can be avoided in the first processing step. Therefore, the uncertain state is treated separately in a further operation.

Picture elements are assigned to the unchanged state, if the absolute frame difference is below a certain threshold T_1 and to the changed state, if the absolute frame difference is beyond another certain threshold $T_2 > T_1$. The remaining picture elements are assigned to the uncertain state. The selection of the thresholds T_1 and T_2 has to be adapted to the noise amplitude in the image sequence.

To obtain a binary mask distinguishing only between changed and unchanged picture elements, an elimination of singular uncertain elements is performed and non-singular uncertain elements are assigned to the changed region. An element is defined to be singular, if this element is of one type, changed or unchanged or uncertain, and at least six direct neighbouring elements are of another type, that means unchanged or changed. Thus, each of the singular uncertain elements is assigned either to the unchanged area, if the neighbouring picture elements are of the changed type or to the changed area, if the neighbouring picture elements are of the unchanged type. The remaining uncertain elements are assigned to the changed region. Now there exists a binary mask distinguishing between changed and unchanged elements for each picture element of the two transmitted fields.

In the following step a median filter is applied, using measurement windows of the size of N by N picture elements. If $N^2/2+1$ picture elements of the mask belong to the changed area, the picture element in the center of the window is assigned to the changed area too or vice versa. This filter can be implemented as a simple counting operation. The median filtering smoothes the boundaries between the changed and the unchanged area. Further, small regions misdecided in the previous steps are corrected.

In the last processing step, named elimination of singular elements, still remaining singular elements are reassigned to the state of the neighbouring elements.

Fig. 8 shows an example for the change detection mask, obtained by computer simulations. The thresholds for the change detector are choosen to $T_1=3/256$ and $T_2=6/256$, where 256 is due to the quantization according to 8 bit per sample. The median filtering is performed using a window size of 5 by 5 picture elements. The resulting change detection mask is preserving the moving objects in the changed regions in its entirety and is adapting well to the boundaries of the moving objects.

5. Motion compensating interpolation filter

The motion compensating interpolation filter calculates each picture element of the fields to be interpolated by means of two transmitted fields and by means of the estimated horizontal and vertical displacement vector components (Fig. 1). Because of the integral displacement vector components (see Section 3.1) the filter reduces to a two-coefficient spatio-temporal filter.

With help of the integral displacement vector components estimated for the position x,y, first the addresses of the corresponding picture elements in the transmitted fields are determined. They are needed to calculate the picture element at the position x,y in the field to be interpolated. The displacement vector as well as the two picture elements are multiplied by weighting factors, that correspond to the temporal distances between the field to be interpolated and the transmitted fields. Then the picture element to be interpolated results from the addition of the two weighted picture elements.

Fig. 9 illustrates the operation of the MCI-filter algorithm. The transmitted fields have the associated temporal position $t=0$ for field k-l and $t=1$ for field k. The intermediate position $t=\tau$ with $0 \leq \tau \leq 1$ is corresponding to the temporal distance of the field to be interpolated to the field k-l. Each picture element of the field to be interpolated is calculated as a function of the displacement vector components and the temporal position τ as

$$S(x,y,\tau) = \{1-\tau\}\bullet S_{k-l}(x-\tau\bullet \hat{d}x, y-\tau\bullet \hat{d}y) + \tau\bullet S_k(x-\{1-\tau\}\bullet \hat{d}x, y-\{1-\tau\}\bullet \hat{d}y)$$

with (5)

$0 \leq \tau \leq 1$.

The displacement vectors estimated by means of the luminance data only are also used to interpolate the chrominance signals.

6. Experimental results

6.1 Test sequences

The presented motion compensating field interpolator has been experimentally investigated by means of computer simulations. Two typical video conference scenes with 50 Hz field frequency have been used, "Trevor" consisting of 150, and "Split Screen" consisting of 100 fields. These sequences have been selected by the European COST 211bis simulation subgroup for testing of video conference codecs. The original sequences have been sampled at 13.5 MHz for the luminance component (Y) and at 6.75 MHz for each chrominance component (R-Y,B-Y), and uniformly quantized according to 8 bit per sample. For the simulations of the interpolator the horizontal resolution of the luminance and chrominance components has been reduced to one half of the original sampling rate. Thus, every luminance field consists of 288 lines and 312 picture elements per line, the chrominance fields of 288 lines and 156 picture elements per line. Fig. **10** (a) and **11** (a) show the luminance of one original field for each sequence in the specified format. For the aim of data compression the field frequency is reduced to 12.5 Hz by omitting three fields out of four fields at the transmitter. Effects from line-interleaving have not to be concerned as a result of dropping an odd number of successive fields. At the receiver the omitted fields are reconstructed by means of the presented motion compensating interpolator. Finally, the reconstructed sequences are converted to the standard line-interleaving format by vertical filtering of every second field, in order to display the sequences on a standard video monitor.

6.2 Simulation parameters

The problems due to the integer estimation of the displacement vector components, using the symmetrized motion compensating iteration technique at non-centered temporal positions between two available fields, are reduced by interpolating the fields in a special order. First, the second of three omitted fields is interpolated, by itself at the centered temporal position. Then, the other two fields are interpolated, now being at the centered temporal position between one of the originally transmitted fields and that one interpolated before. The luminance data only is used to calculate the displacement vector fields and the change detection masks. The displacement vector fields are applied for both, the interpolation of the luminance and of the chrominance fields.

The parameters for the displacement estimate are listed in Table 1. The impulse responses of the FIR filters, used for the bandlimitation of the image signal, are listed in Table 2. The displacement estimation algorithm is evaluated using the hierarchical structure combined with the symmetrized motion compensating iteration technique. Three steps with distinct parameters are used. In each step three iterations are performed. The displacement vectors are estimated only for a certain subset of picture elements rather than for all spatial positions in each step of the hierarchy. For the other picture elements the vectors are obtained by bilinear interpolation, calculating a distance-weighted average of the nearest four vectors belonging to the rectangular grid, the vector field has been estimated for. The magnitude of the displacement vector components is limited to 60 picture elements in the x-and y-direction.

6.3 Discussion of the results

The sequences, reconstructed by the presented motion compensating interpolator, have been compared to results obtained without motion compensation. For this purpose, the sequences have been displayed on a video monitor using a real-time image display system. The sequences obtained by linear interpolation as well as those, generated by field repetition, show visible degradations. The picture quality is degraded as a result of the relatively large amount of motion. The motion compensating interpolation technique yields unblurred moving objects widely preserving the natural impression of motion. In order to give an impression of the performance of the proposed approach, several photos taken from the television screen are presented as monochrome pictures.

In Fig. **10** (a) and **11** (a) one original field of the sequence "Trevor" and "Split Screen" is shown. In order to demonstrate the amount of motion, the frame difference signals between the two transmitted fields, used as input data for the interpolator, are shown for both sequences in Fig. **10** (b) and **11** (b). The fields, generated for the centered temporal position between the two transmitted fields by means of linear

interpolation, are shown in Fig. **10** (c) and **11** (c). Blurring can be recognized in all moving areas. The results, obtained by using the described interpolator with the hierarchically structured displacement estimator are shown in Fig. **10** (d) and **11** (d).

7. Conclusion

An algorithm for motion compensating field interpolation in digital television sequences is presented. Linear interpolation and field repetition techniques without motion compensation yield visible degradations as blurring and jerkiness. In order to avoid these effects, the motion of objects has to be taken into account.

A hierarchically structured displacement estimator is presented, which is able to cope with large displacements by means of motion compensating iterations. It is shown, that the evaluation of the estimation algorithm on large measurement windows combined with a lowpass filtering of the image signal in the first steps of the hierarchy increases the reliability of the estimation results. The computational complexity due to the large windows can be decreased by subsampling the filtered image contents according to the bandlimitation. A symmetrized iteration technique enables to provide displacement vector fields, which are defined for the fields to be interpolated. Erroneous non-zero vectors in unchanged areas may cause jitter. They are suppressed by a special change detector. Using these vector fields for the motion-compensating interpolation, the rendition of motion is remarkably improved when compared to known interpolation techniques.

The described interpolation scheme allows the unblurred reconstruction of several fields between every two transmitted fields using integer displacement vector components. The evaluation of nearly 200 fields, interpolated by computer simulations for the case of transmitting only every fourth field of a sequence, show that the natural impression of motion is widely preserved. Some remaining visible artefacts are due to large displacements of more than 60 picture elements or non-translatory motion, which are not sufficiently approximated by displacement vectors.

The remarkably improved picture quality achieved by the presented interpolator has to be payed by a relatively complex algorithm, however.

The method according to the invention can be used for the following purposes: For the reconstruction at the receiver's end of one or more omitted television images between every two transmitted fields of a digital television sequence; for the generation of one or more additional fields between every two successive images; for the motion compensating noise reduction of digital television sequences.

References

[1] G. Kummerfeldt, F. May, W. Wolf, "Coding Television Signals at 320 and 64 kbit/s", **2nd Int. Tech. Symposium on Optical and Electro-Optical Applied Science and Engineering,** Cannes, December 1985.

[2] B. G. Haskell, R. L. Schmidt, "A low bit-rate interframe coder for videotelephone", **Bell Syst. Techn. J.,** Vol. 54, No. 8, pp. 1475-1495, Oct. 1975.

[3] J. Klie, "Codierung von Fernsehsignalen für niedrige Übertragungsbitraten", Ph.D. dissertation, Tech. Univ. of Hannover, Hannover, Germany, 1978.

[4] H.G. Musmann, P. Pirsch, and H.-J. Grallert, "Advances in Picture Coding", **Proc. of the IEEE,** vol. 73, pp. 523-548, Apr. 1985.

[5] J. R. Jain, A. K. Jain, "Displacement measurement and its application in interframe image coding", **IEEE Trans. on Comm.,** Vol. Com-29, No. 12, pp. 1799-1808, Dec. 1981.

[6] A. Furukawa, T. Koga, K. Iinuma, "Motion-adaptive interpolation for videoconference pictures", **Proc. of the Int. Conf. on Comm. 1984,** pp 707-710, Amsterdam, 1984.

[7] H. C. Bergmann, "Motion adaptive frame interpolation", **Proc. of the 1984 Int. Zurich Seminar on Digital Communications,** D2.1 -D2.5, Zurich, 1984.

[8] M. Bierling, "A Differential Displacement Estimation Algorithm with Improved Stability", **2nd Int. Tech. Symposium on Optical and Electro-Optical Applied Science and Engineering,** Cannes, December 1985.

[9] C. Cafforio, F. Rocca, "Methods for measuring small displacements of television images", **IEEE Trans. Inform. Theory,** Vol. IT-22, No. 5, pp. 573-579, Sept. 1976.

[10] C. Cafforio, F. Rocca, "The differential method for image motion estimation", **Image Sequence Processing and Dynamic Scene Analysis**, edited by T.S. Huang, Berlin, Germany: Springer-Verlag, pp. 104-124, 1983.

[11] B. Girod, R. Thoma, "Motion-compensating field interpolation from interlaced and non-interlaced grids", **2nd Int. Tech. Symposium on Optical and Electro-Optical Applied Science and Engineering**, Cannes, December 1985.

[12] S. Beyer, "Displacement-Schätzverfahren für Fernsehbildsignale mit minimaler Schätzfehlervarianz", Ph.D. dissertation, Univ. of Hannover, Hannover, Germany, 1985.

[13] A. N. Netravali, J. D. Robbins, "Motion compensated television coding-Part I", **Bell Syst. Techn J.**, Vol. 58, pp. 631-670, Mar. 1979.

[14] R. Paquin, E. Dubois, "A spatio-temporal gradient method for estimating the displacement vector field in time-varying imagery", **Computer Vision, Graphics, and Image processing 21**, pp. 205-221, 1983.

Table 1

Parameters for the hierarchically structured displacement estimator as used for the simulations.
WV,WH = Height and width of the rectangular measurement windows (in picture elements).
F = Name of the filter used for the bandlimitation of the image signal. The impulse responses are listed in Table 6.2.
SF = Factor the image contents of the measurement windows are subsampled by.
I = Number of iterations performed in each step of the hierarchy.
GV,GH = Vertical and horizontal distance between the picture elements belonging to the grid the displacement vector field is estimated for.

Step of hierarchy	WV , WH	F	SF	I	GV , GH
1	65 , 65	FIL1	4	3	8 , 8
2	27 , 27	FIL1	4	3	4 , 4
3	13 , 13	FIL2	2	3	2 , 2

Table 2

Impulse responses of the digital FIR filters used for the bandlimitation of the image signal.

Filter	Impulse response
FIL1	-13 , -9, 8, 37, 66, 78, 66, 37, 8, -9,-13
FIL2	13 , -1,-25, -1, 79,126, 79, -1,-25, -1, 13

Claims

1. A method of motion compensating field interpolation of one or more fields between every two transmitted fields of a digital television sequence comprising the steps of:
-generating a displacement vector by an iteration process for each picture element of the field to be interpolated,
-assigning zero displacement vectors in unchanged picture areas by means of a change detector, characterised in that:
-a hierarchically structured displacement estimation is applied to cope with large displacements, wherein after motion compensation by means of the vector estimated in the first steps of iteration the residual displacement is estimated in the next steps more precisely and wherein the displacement vector is provided with integer components,
-a symmetrized motion compensating iteration is carried out resulting in displacement vectors defined for a temporal position of the fields to be interpolated in such a way, that an interpolation filter interpolates each picture element of the fields to be interpolated by means of a displacement vector and a picture element of every two transmitted fields.

2. A method according to claim 1, wherein in the first steps of the hierarchically structured displacement estimation the image signal is low-pass filtered and large measurement windows are applied to estimate large displacements, which serve as initial values for the next steps of the iteration process, and wherein in the last steps of the hierarchically structured displacement estimation the unfiltered image signal and small measurement windows are applied to estimate the displacement vector components locally adaptive.

3. A method according to claim 1 or 2, in which the change detector information, processed by a threshold operation applied to the absolute frame differences with an assignment for every picture element to belong either to the unchanged area or to the changed area, is post-processed by means of a median filter using measurement windows in such a way, that the boundaries between changed and unchanged areas of a binary change detection mask is adapted to the boundaries of the moving objects.

4. Use of the method according to claims 1, 2 or 3 for the reconstruction at the receiver's end of one or more omitted television images between every two transmitted fields of a digital television sequence.

5. Use of the method according to claims 1, 2 or 3 for the generation of one or more additional fields between every two successive images.

6. Use of the method according to claims 2 or 3 for the motion compensating noise reduction of digital television sequences.

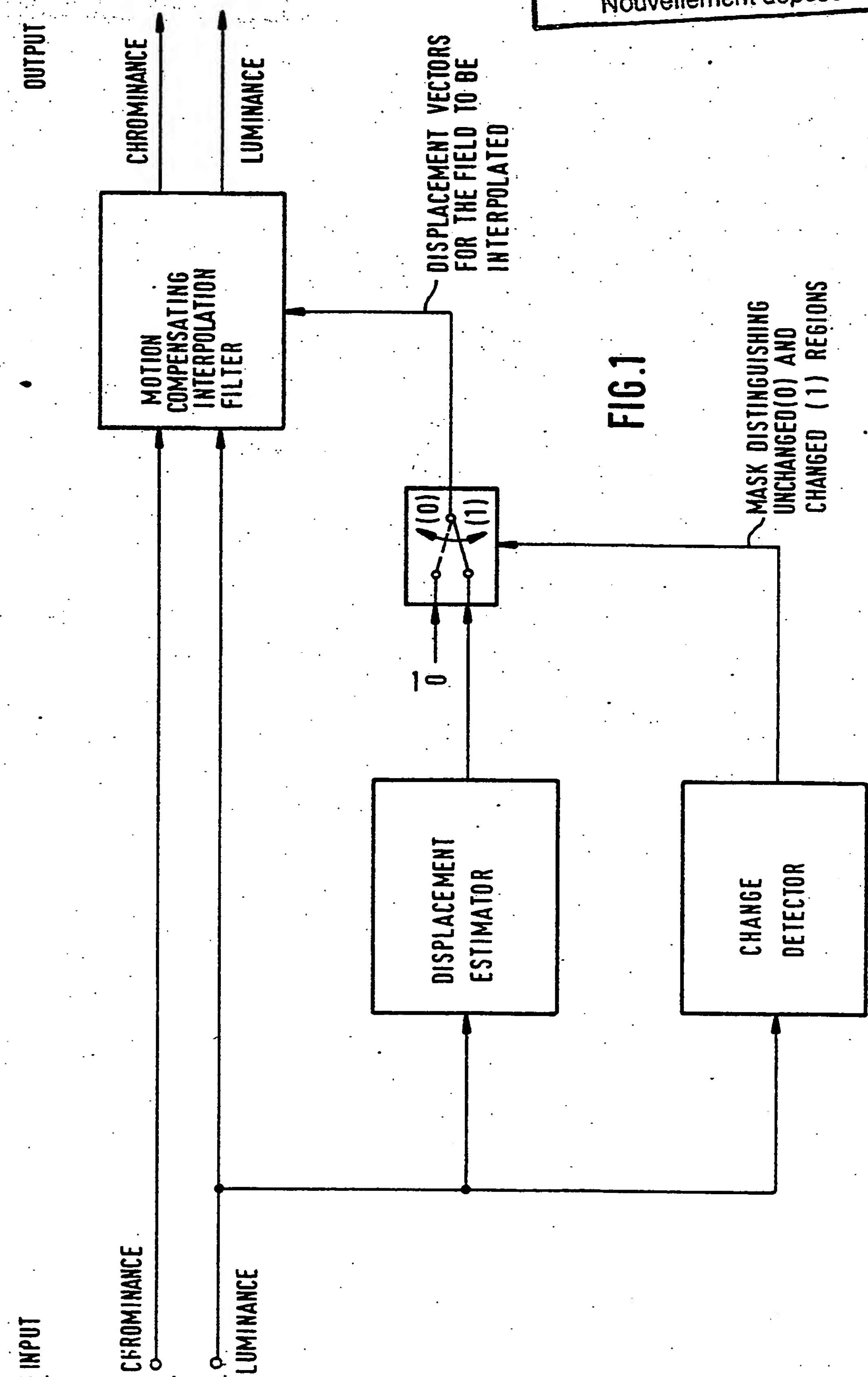

OUTPUT
CHROMINANCE
LUMINANCE
MOTION COMPENSATING INTERPOLATION FILTER
DISPLACEMENT VECTORS FOR THE FIELD TO BE INTERPOLATED
(0)
(1)
1 0
MASK DISTINGUISHING UNCHANGED(0) AND CHANGED (1) REGIONS
DISPLACEMENT ESTIMATOR
CHANGE DETECTOR
INPUT
CHROMINANCE
LUMINANCE

FIG.1

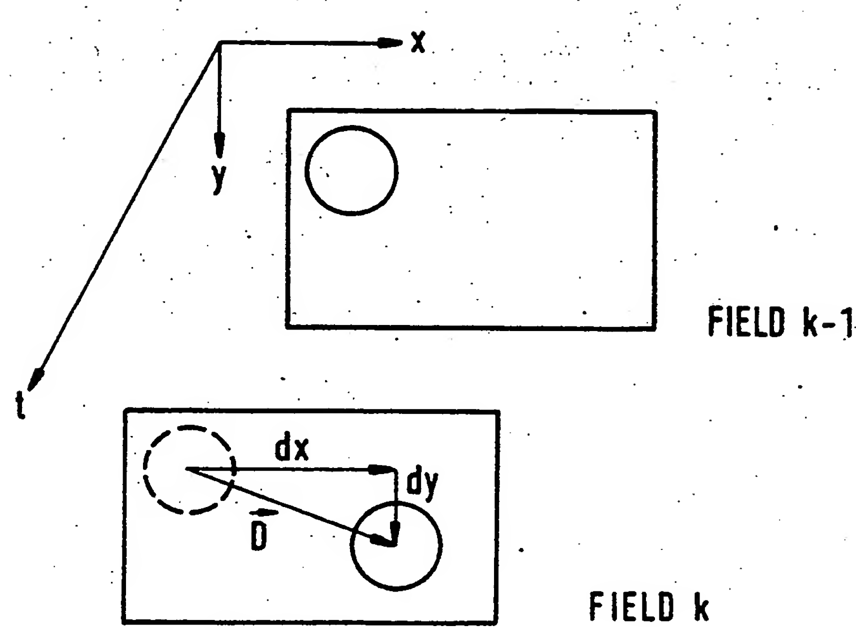


FIG. 2

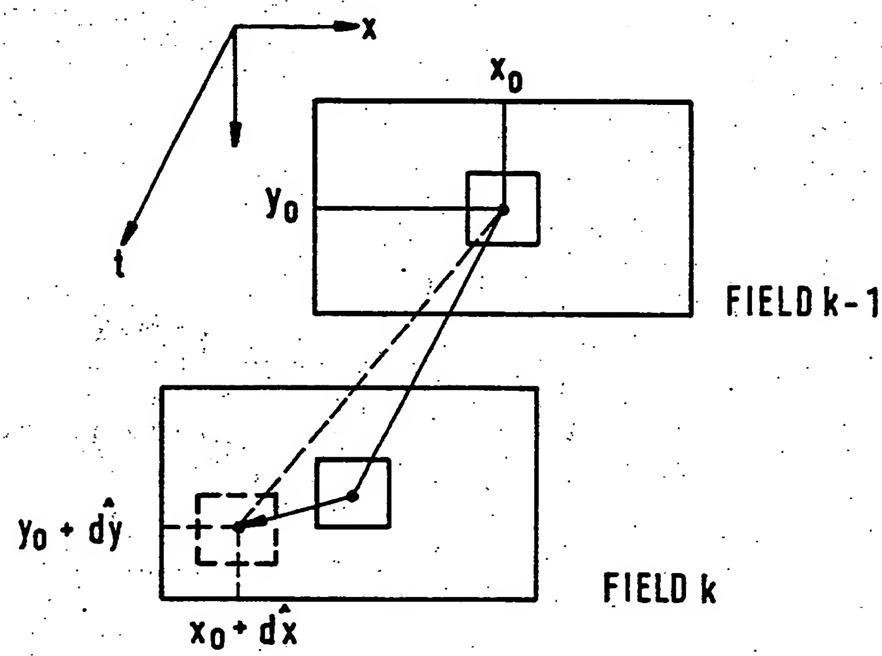

x
t
x_0
y_0
FIELD k-1
$y_0 + d\hat{y}$
FIELD k
$x_0 + d\hat{x}$

FIG. 3A

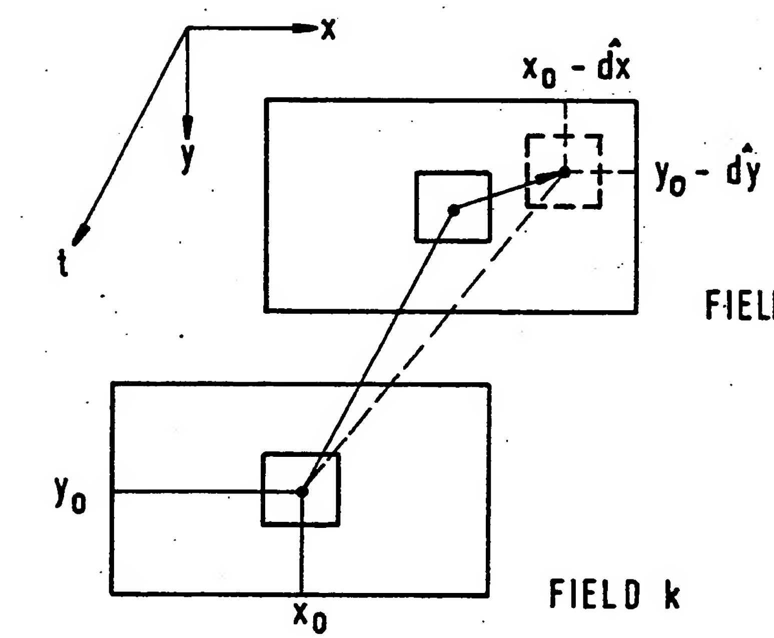

x
y
t
$x_0 - d\hat{x}$
$y_0 - d\hat{y}$
FIELD k-1
y_0
FIELD k
x_0

FIG. 3B

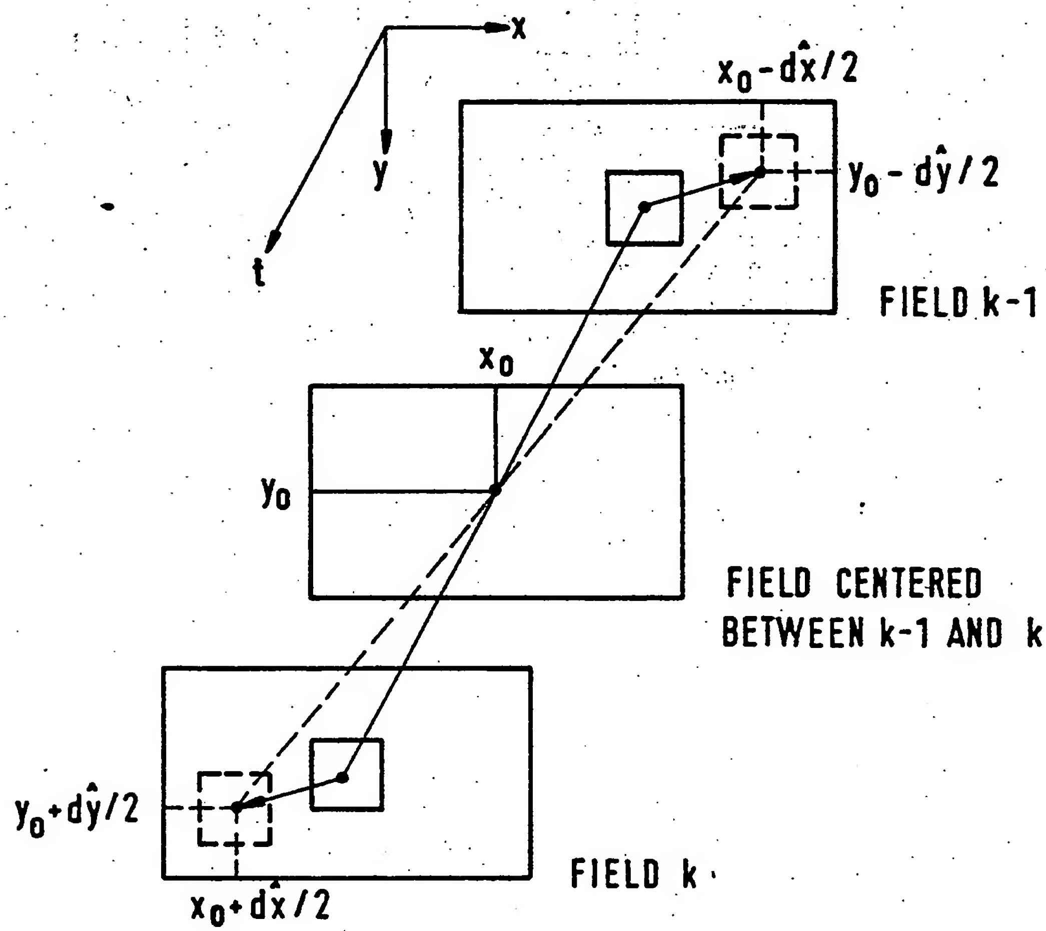

x
y
t
$x_0 - d\hat{x}/2$
$y_0 - d\hat{y}/2$
FIELD k-1
x_0
y_0
FIELD CENTERED BETWEEN k-1 AND k
$y_0 + d\hat{y}/2$
$x_0 + d\hat{x}/2$
FIELD k

FIG. 3C

Neu eingereicht / Newly filed
Nouvellement déposé

FIG. 4A

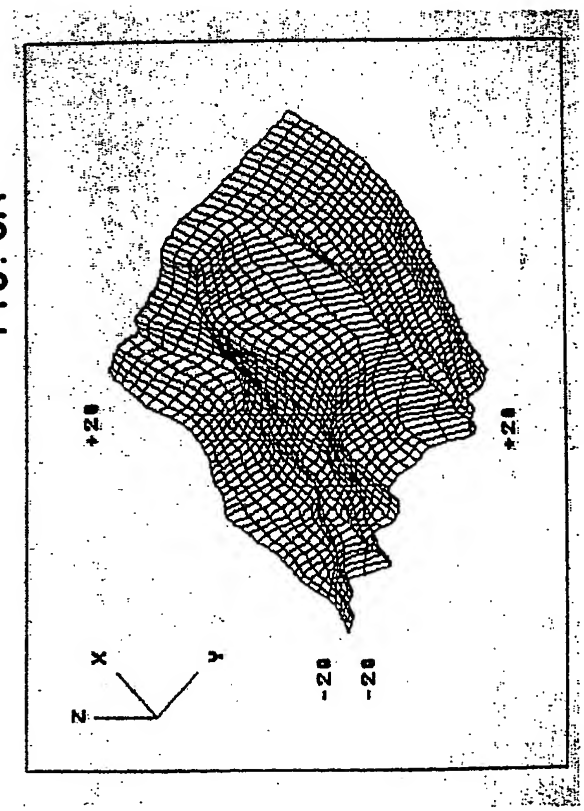


FIG. 5A

FIG. 4B

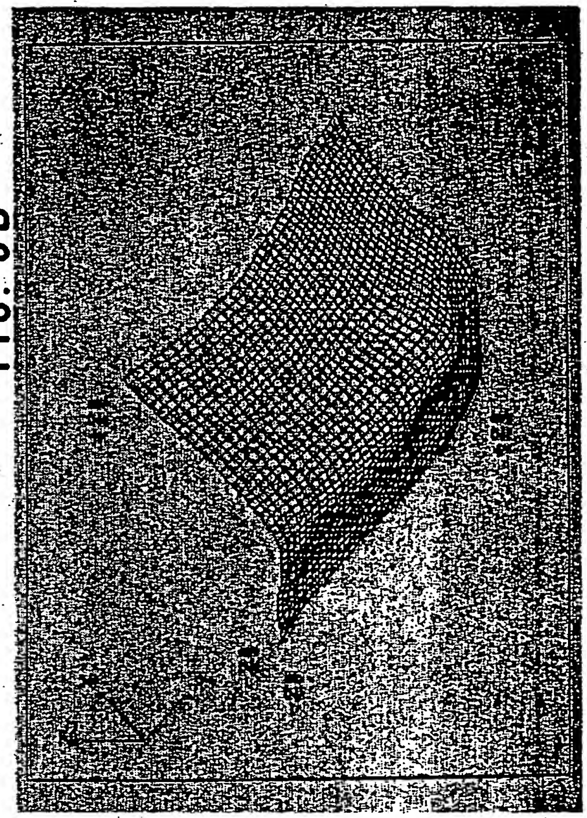


FIG. 5B

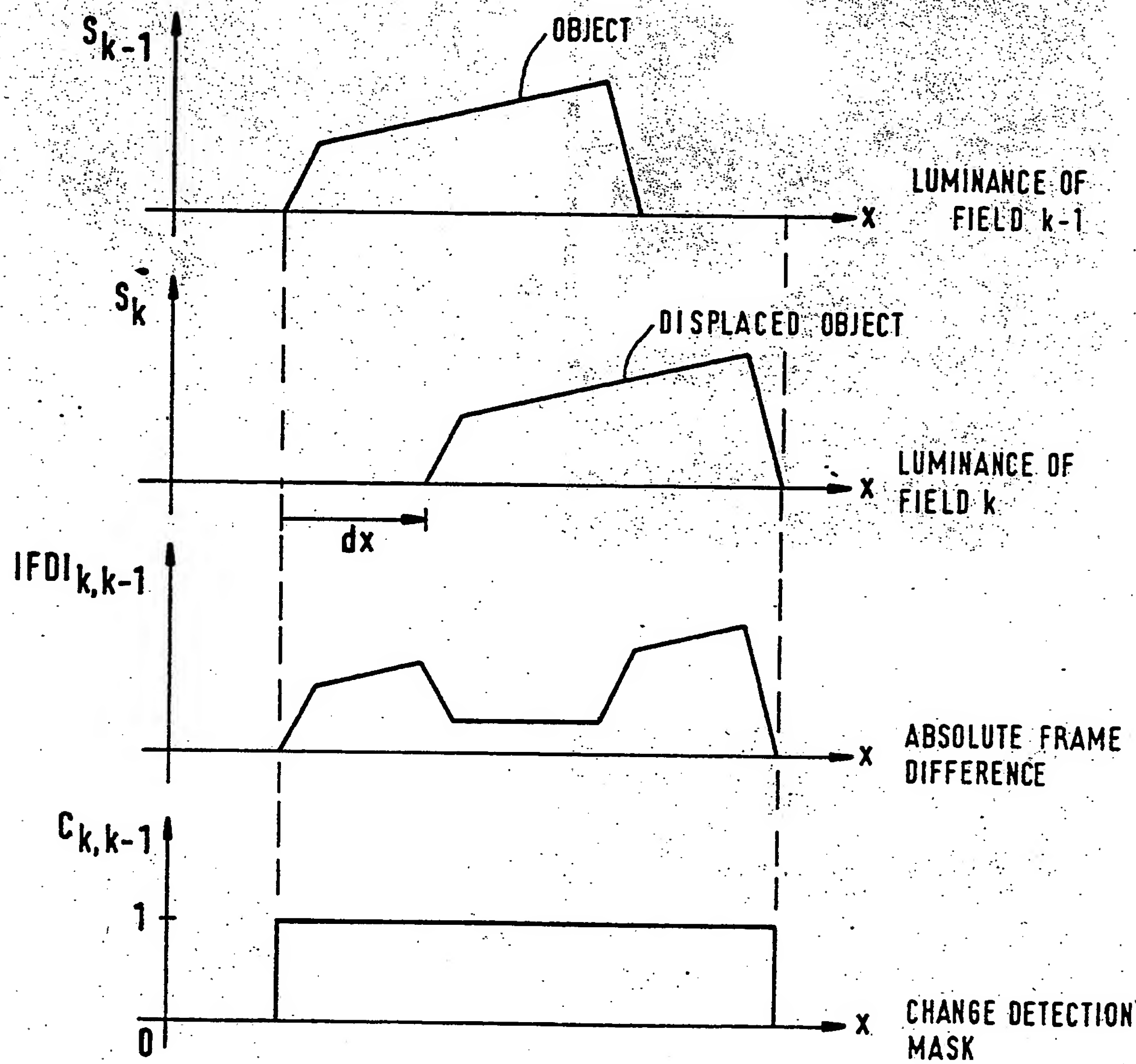
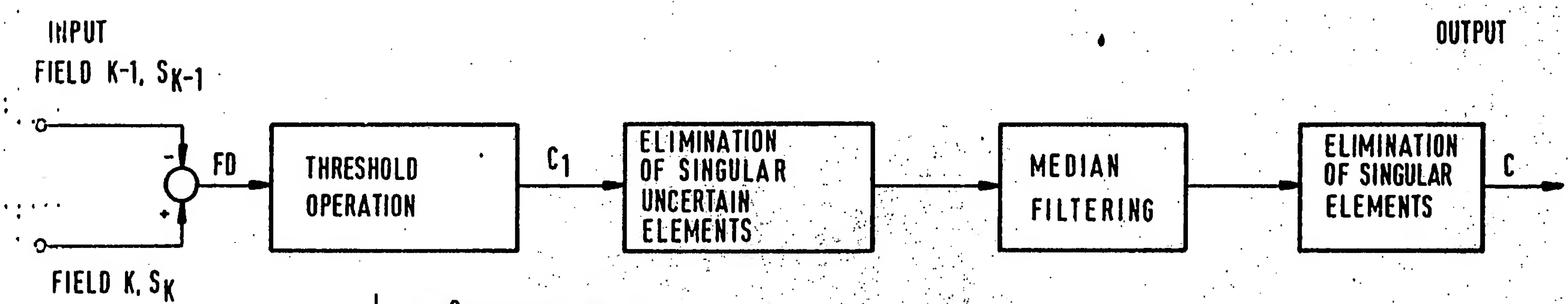
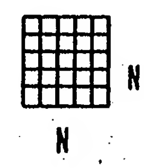

S_{k-1}
OBJECT
LUMINANCE OF
FIELD k-1
x
S_k
DISPLACED OBJECT
LUMINANCE OF
FIELD k
x
dx
$|FD|_{k,k-1}$
ABSOLUTE FRAME
DIFFERENCE
x
$C_{k,k-1}$
1
0
CHANGE DETECTION
MASK
x

FIG. 6



	C_1
$\lvert FD \rvert < T_1$	0 ≙ UNCHANGED
$T_1 \leqslant \lvert FD \rvert \leqslant T_2$	X ≙ UNCERTAIN
$\lvert FD \rvert > T_2$	1 ≙ CHANGED



S_K, S_{K-1} : LUMINANCE SIGNALS

FD : FRAME DIFFERENCE

C : CHANGE DETECTION MASK DEFINED FOR EACH PICTURE ELEMENT

C = 1 ≙ CHANGED

C = 0 ≙ UNCHANGED

FIG. 7

FIG. 8

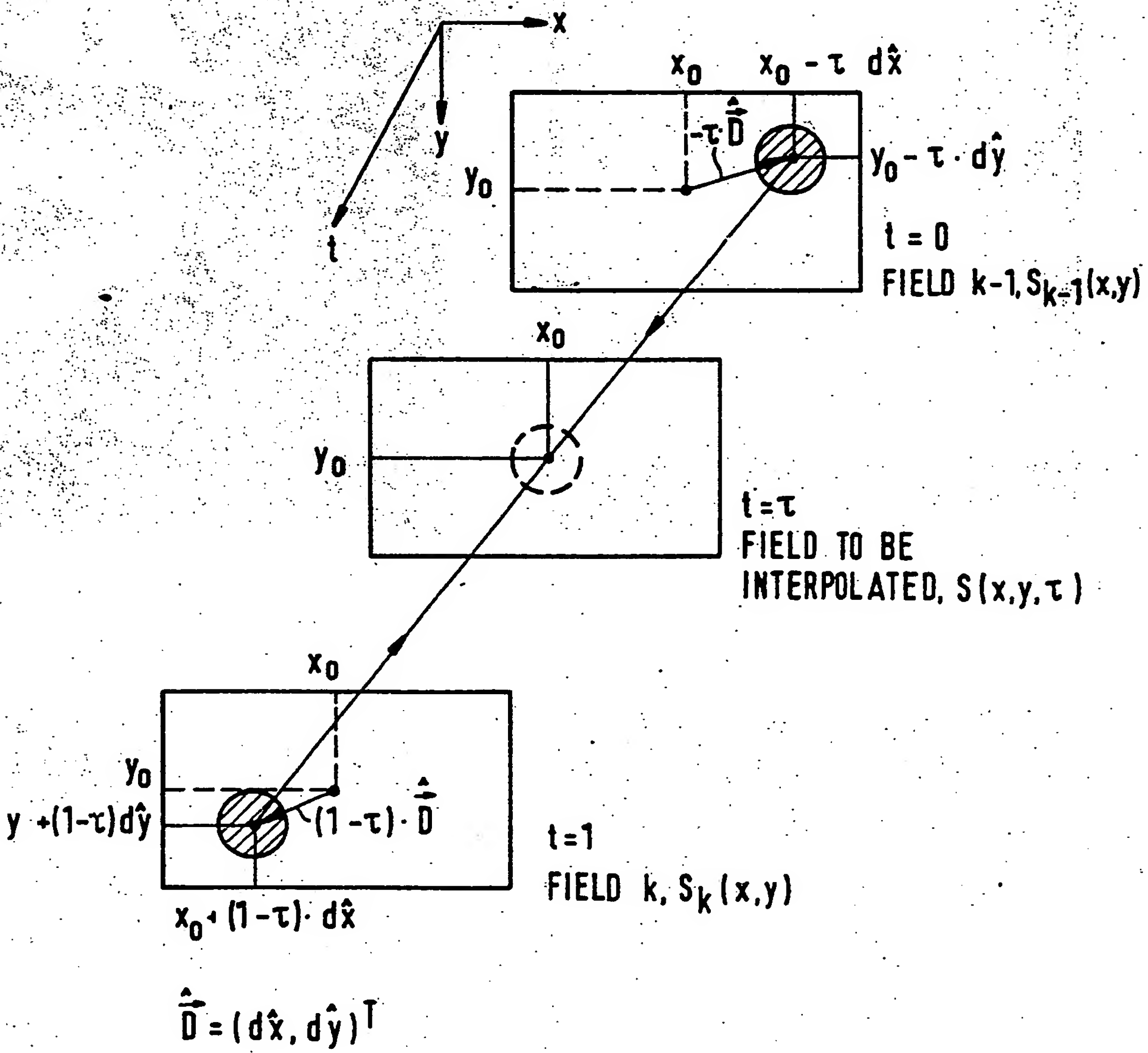

x
y
t
x_0
$x_0 - \tau\ d\hat{x}$
$-\tau \cdot \hat{\vec{D}}$
y_0
$y_0 - \tau \cdot d\hat{y}$
t = 0
FIELD k-1, $S_{k-1}(x,y)$
x_0
y_0
t = τ
FIELD TO BE INTERPOLATED, $S(x,y,\tau)$
x_0
y_0
$y + (1-\tau) d\hat{y}$
$(1-\tau) \cdot \hat{\vec{D}}$
t = 1
FIELD k, $S_k(x,y)$
$x_0 + (1-\tau) \cdot d\hat{x}$
$\hat{\vec{D}} = (d\hat{x}, d\hat{y})^T$

FIG. 9

FIG. 10A

FIG. 10B

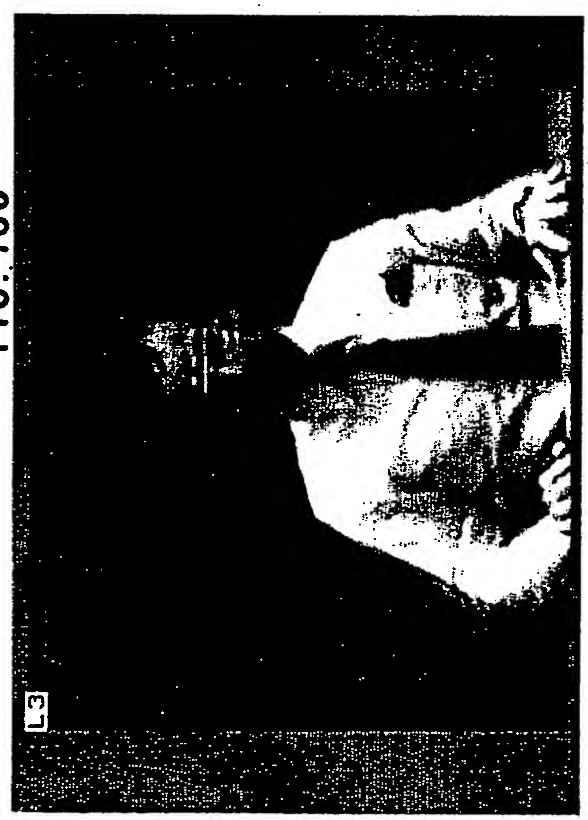


FIG. 10C

FIG. 10D

FIG. 11A

FIG. 11B

FIG. 11C

FIG. 11D